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Effect of Alkyd Varnish on the Thermal Stability and Static Smoke Properties of Decorative Wood

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Abstract

The effect of alkyd varnish on thermal stability and static smoke properties of decorative wood were analysed by using thermo-gravimetric (TG) analyzer, differential scanning calorimeter and plastic smoke density tester. The TG results show that maximum mass loss of the wood and alkyd varnish occurs in the range of 200-500℃. At the pyrolysis stage, the alkyd varnish exhibits an obvious endothermic process, while the wood exhibits an obvious endothermic process and then an exothermic one. The infrared analysis and smoke density test show that the olefin structure and benzene ring structure of alkyd varnish increase both the special optical density and mass optical density of the decorative wood consisted alkyd varnish. Meanwhile, the higher external heat flux and application of an ignition source decrease the special optical density and mass optical density of the decorative materials.

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Keywords: Alkyd varnish, decorative wood, pyrolysis characteristic, static smoke property

1. Introduction

Decorative wood is popular used in building interior decoration, owing to its unique advantages such as natural and beautiful texture. However, the poor fire resistance of wood restricts its application in many fields [1]. In addition, various varnishes especially alkyd varnish are widely used to improve processing quality [2]. However, most varnishes are organic polymer, and the high flammability and smoke density of varnishes will increase the heat release and smoke production [3]. In general, the smoke is the main reason to cause death in a fire. Therefore, it is significant to study the effects of decorative wood consisted varnish on the generation of smoke [4]. Currently, light extinction is widely used to measure smoke properties, and the results measured by light extinction can evaluate the hazard of smoke development to visibility. The test results of light extinction is related to the smoke scenario in real fire, and can be used to design the fire safety route [5]. Light extinction also employs dynamic and static methods, which the typical static test employ NBS chamber according to ISO5659-2 “Plastics -- Smoke generation -- Part 2: Determination of optical density by a single-chamber test” [6]. The static method mainly measures the variation of smoke transparency during the combustion of materials, and then calculates the special optical density and mass optical density to evaluate the static smoke properties [7]. The larger value of special optical density and mass optical density, and the higher smoke production are. At present, the pyrolysis characteristics, pyrolysis kinetics, combustion performance and smoke properties of wood and fire retardant products have been studied more, but rarely on the research of combustion performance and smoke properties of decorative wood consisted alkyd

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varnish [8, 9]. This article mainly studies two typical decorative woods from Phoenix Town. The effect of alkyd varnish on smoke properties of decorative wood was investigated by using smoke density tester, and the relationships between the pyrolysis characteristics and smoke properties of materials were analysed.

2 Experimental

2.1Materials

Decorative materials were acquired from Phoenix Town of Hunan province in China. The decorative materials were including the decorative wood with and without coated alkyd varnish. As shown in Figure1, uncoated alkyd varnish of wood is marked sample A while the coated varnish is remarked sample B. Sample A and the alkyd varnish which was scraped from the sample B were shattered to 200 mesh for thermo-gravimetric analysis (TGA) and differential scanning calorimeter(DSC).

Fig.1 Two decorative wood samples

2.2 Measurements

TGA and DSC were performed using a DT-50(Setaram, France) instrument. About 10mg of sample was put in an aluminum foil at the heating rate of 10K/min from ambient temperature to 750℃ in the nitrogen atmosphere (flow rate of 20mL/min). Static smoke properties were measured by smoke density test (JQMY-2, Jianqiao Co. Ltd, China) according to ISO5659-2006. The sample sizes were 75 mm×75 mm×4 mm and the external heat flux level was chosen 25 and 50kW/m^2 with or without application of an ignition source. FTIR analysis of alkyd varnish was recorded with an IR Prestige-21spectrometer from Shimadzu Corporation, Japan.

3 Results and discussion

3.1 Thermal stability

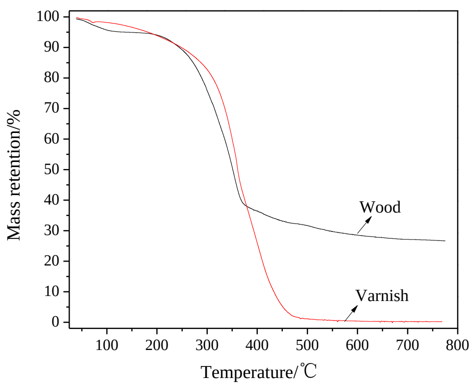


Fig.2 TG curves of decorative wood and varnish

The TG curves of decorative wood and alkyd varnish under nitrogen are shown in Figure 2. TG curve of decorative wood shows three stages during thermal degradation. At the dehydration and volatilization stage, where temperature range is 50-150℃, the most important changes are the volatilization of moisture and volatile and the mass loss is 4.76%. The pyrolysis of cellulose, hemicellulose and lignin in the wood occurs in the second stage in the temperature range of 150-400℃. TG curves indicate the mass loss as high as 60.86% with a rapid decrease. The third stage of carbonization occurs above 400℃

with a mass loss of 9.08%. A large amount of carbon residue is formed with the final number of 25.32% .TG curves decrease slowly in the stage. However, the pyrolysis of alkyd varnish includes two main stages. The small molecular volatilization stage occurs in the temperature range 50-120℃ with a mass loss of 3.05%. In this stage, TG curves appear to be more smoothly. The mass loss of 96.95% in the pyrolysis stage in temperature range 120-500℃ is due to the complete decomposition of alkyd varnish. There is a rapid decline in the TG curve in the stage.

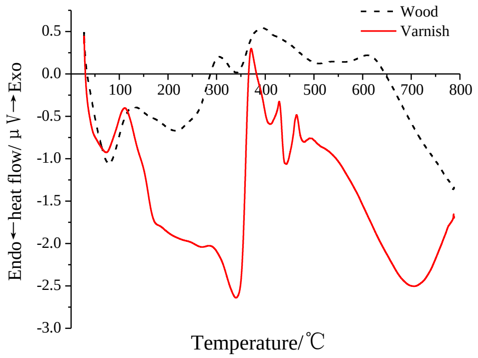
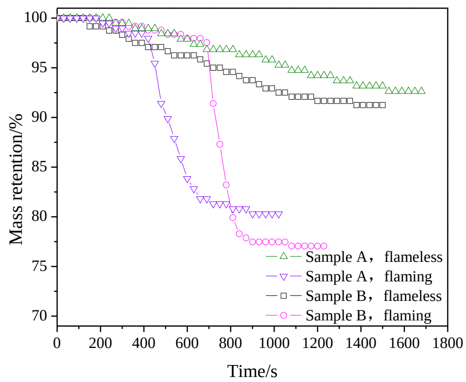


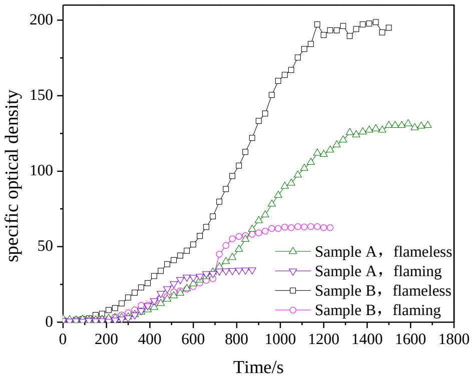
Fig.3 DSC curves of decorative wood and varnish

Figure 3 shows the DSC curves of decorative wood and alkyd varnish under nitrogen. There is a significant endothermic and exothermic process at the pyrolysis staged, which mainly reflects an endothermic process at the dehydration and volatilization. For wood, an endothermic process and then an exothermic one at the pyrolysis stage, then an exothermic process at the carbonization stage are shown in Figure 3. However, the pyrolysis of alkyd varnish exhibits an endothermic process in two stages which need to absorb a lot of heat. In summary, The TG results show that maximum mass loss of the wood and alkyd varnish occurs in the range of 200-500℃. At the pyrolysis stage, the alkyd varnish exhibits an obvious endothermic process, while the wood exhibits an obvious endothermic process and then an exothermic one.

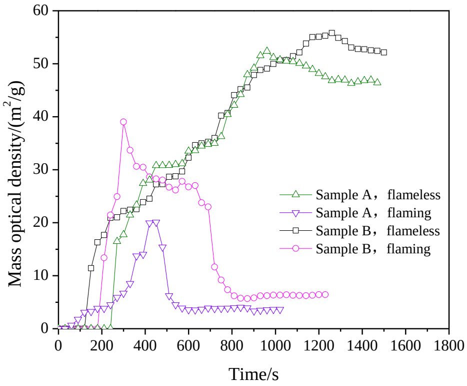
3.2 Static smoke properties



(a) Mass retention curves



(b) Special optical density curves



(c) Mass optical density curves

Fig.4 Mass retention, specific optical density and mass optical density curves of the samples at 25kW/m^2 external heat flux

The mass retention, specific optical density and mass optical density curves of the samples at 25kW/m^2 external heat flux are shown in Figure 4. As shown in Figure 4, the application of an ignition source increase the mass loss of decorative wood, while decreae the specific optical density and mass optical density. It can be illustrated that the decomposition of materials is related to an endothermic process. The thermal feedback of combustion flame promotes the decomposition of the material, so an ignition source can increase the mass loss. Moreover, the combustible gas of flameless combustion will not further burning, and the pyrolysis products resolve into CO, CO_2 and other small molecules by way of further oxidative decomposition with an ignition source which increases the transmittance. So the specific optical density is reduced and the mass retention is incresed in flaming combustion, which further led to the decreasing of mass optical density. Furthermore, the mass retention, specific optical density and mass optical density of the sample B are higher than that of sample A, which increases the smoke hazard of the wood coated with varnish and the fire hazard. Combined with TG experiment, the varnish decomposes completely during pyrolysis and the pyrolysis products in the combustion process also produce a lot of heat in order to promote the wood cracking, thus it can be illustrated that the mass loss of sample B is higher than that of sample A in smoke density test. Combination with the infrared spectrum of alkyd varnish in Figure 5, alkyd resins exhibit bending vibration bands of olefin C-H at 700cm^{-1}-800cm^{-1}, framework vibration of aromatics C=C at 1466cm^{-1} and expansion bands of olefin C=C at 1638cm^{-1}.The olefin structure and benzene ring structure make the alkyd resins generate graphitized carbon particles by cyclization and polycondensation in the combustion ,which tend to form smoke particles and obstruct the ray propagation to reveal a higher specific optical density. It is worth noting that the alkyd varnish resolve into small molecule at 50-120℃ which will rise in the air and form condensed matter with moisture and volatile volatilized by wood at the dring and dehydration and volatilization,which will be converted to gaseous products while burning in the air and smoke particles under hypoxic conditions or low temperature to increase the specific optical density of materials. In addition, alkyd resins only crack but not combust without flame and the pyrolysis products themselves constitute the smoke. In particular, the smoke composed of graphitized carbon particles can significantly increase the specific optical density of materials.

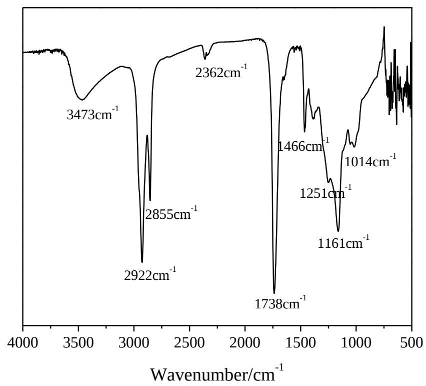
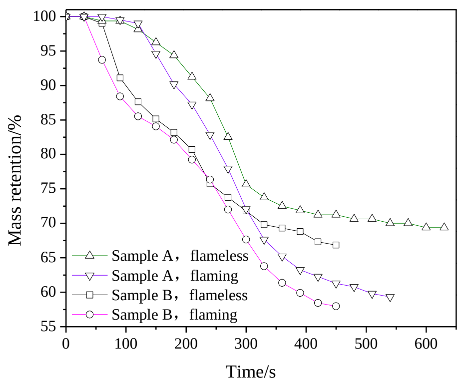
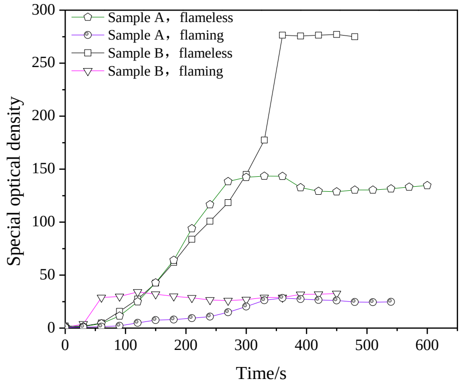


Fig.5 Infrared Spectroscopy of varnish

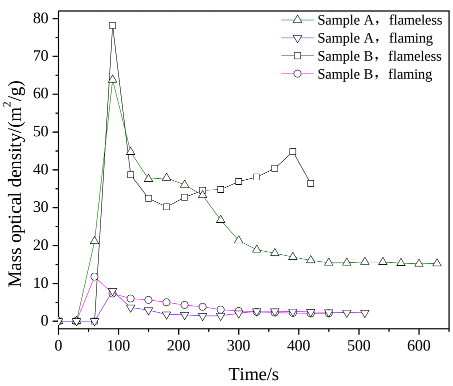
The mass retention, specific optical density and mass optical density curves of the samples at 50kW/m^2 external heat flux are shown in Figure5. It can be seen that the specific optical density and mass optical density with an ignition source at 50kW/m^2 are lower than that without an ignition source, and the mass retention with an ignition source is higher than that without an ignition source as shown in Fig.6. In addition, the mass retention, specific optical density and mass optical density of sample B are obviously higher than that of sample A at the heat flux of 50kW/m^2. The similar results also can be illustrated at the heat flux of 25kW/m^2. It is noted that the mass optical density of decorative wood under the higher external heat flux reaches the maximum at approximate 50-150s and then decreases rapidly as shown in Figure 6(b). This phenomenon indicates that it is irrationality to take 600s of the MOD to assess the smoke properties of materials according to GB/T8323-2008. The smoke properties of materials should be further analysed by mass retention, specific optical density and mass optical density of decorative materials on different combustion models and external heat flux, and the values are listed in Table 1.



(a) Mass retention curves



(b) Special optical density curves



(c) Mass optical density curves

Fig.6 Mass retention, specific optical density and mass optical density curves of the samples at 50kW/m^2 external heat flux

As shown in Table 1, the maximum mass retention, specific optical density and mass optical density of sample B are obviously higher than that of sample A at 25kW/m^2 and 50kW/m^2. Meanwhile, the maximum mass retention, specific optical density and mass optical density of both sample A and sample B with flame are significantly lower than that without flame and decrease with the increase of external heat flux. Combination with Figure 5 and Figure 6, the decomposition of decorative materials arrive obviously earlier at high external heat flux with flame relative to that at low external heat flux without flame and the mass retention, Ds and MOD reach the maximum in a short time, consistent with the ignition time in the test. The phenomenon is due to the fact that wood and alkyd varnish mainly exhibit endothermic process during pyrolysis, therefore the more the materials are heated, the faster they crack at high external heat flux with flame, which leads to a higher mass loss. More radiation heat can promote pyrolysis products oxidized to small molecule, which causes a lower specific optical density and mass optical density. However, specific optical density and mass optical density of the sample B increase with the increase of unit mass of aromatic hydrocarbons decomposed from alkyd varnish during the combustion. The olefin structure and benzene ring structure of the alkyd resins generate graphitized carbon particles by cyclization and polycondensation during the combustion, which increases the fire hazard of decorative materials coated with alkyd varnish. Moreover, a higher specific optical density of sample B at low external heat flux without flame is related to the smoke particles transformed by condensed matter under hypoxic conditions or low temperature, which is formed by small molecule pyrolysed by alkyd varnish and volatile volatilized by wood.

Table 1 Test parameters of decorative materials on different combustion models and external heat flux

Samples	Heat Flux(kW/m^2)	Ds_{max}		MOD_{max}/(m^2/g)		W_{max}/(%)	
		flameless	flame	flameless	flame	flameless	flame
A	25	131.4	34.7	52.35	19.95	7.37	19.69
	50	143.5	28.3	63.82	8.03	31.25	40.69
B	25	198.6	63.2	55.81	39.02	8.75	22.95
	50	277.1	34.1	78.14	11.76	33.17	42.03

Note：Ds_{max}-the maximum of special optical density, MOD_{max}- the maximum of mass optical density, W_{max}- the maximum of mass loss

4 Conclusions

This paper investigated the effect of alkyd varnish on the static smoke properties of decorative wood. The study shows that the pyrolysis of the decorative wood selected from Phoenix Town demonstrates three stages, the dehydration and volatilization, pyrolyzation and carbonization, whereas the pyrolysis of alkyd varnish includes two main stages, the small molecular volatilization stage and the pyrolysis stage. The mass loss of the wood and alkyd varnish occurs in the range of 200-500℃. At the pyrolysis stage, the alkyd varnish exhibits an obvious endothermic process, while the wood exhibits an obvious endothermic process and then an exothermic one. The infrared analysis and smoke density test show that the olefin structure and benzene ring structure of alkyd varnish increase mass retention, specific optical density and mass optical density in the smoke density test, which also increases the smoke hazard. Meanwhile, the flame conditions and external heat flux make the smoke properties of decorative wood significantly different, and the higher external heat flux and application of an ignition source obviously decrease the mass retention, special optical density and mass optical density of the decorative materials.

Acknowledgement

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